STARTING DEVICE AND STARTING METHOD FOR A SINGLE-PHASE
INDUCTION MOTOR.

Field of the Invention
The present invention refers to an electronic starting
5   device of the type used in electric motors,
particularly in single-phase induction motors.
Background of the Invention
Single-phase induction motors are widely used, due to
their simplicity, strength and high performance. They
10   are generally found in household appliances, such as
refrigerators, freezers, air conditioners, hermetic
compressors, laundry machines, pumps, fans, and in
some industrial applications.
The known induction motors are usually provided with a
15   cage type rotor and a coiled stator having two
windings, one for the running coil and the other for
the starting coil. During the normal operation of the
compressor, the running coil is supplied by an AC
voltage and the starting coil is temporarily supplied
20   at the beginning of the starting operation, creating a
turning magnetic field in the air gap of the stator, a
necessary condition to accelerate the rotor and start
the motor.
This turning magnetic field can be obtained by
25   supplying the starting coil with a current that is
time-displaced in relation to the current circulating
in the main coil, preferably at an angle close to 90
degrees. This time-displacement between the current
circulating in both coils is achieved by constructive
30   characteristics of the coils or by installing an
external impedance in series with one of the coils,
but generally in series with the starting coil. The
value of this current circulating through the starting
coil during the starting process of the motor is
35   generally high, requiring the use of some type of

switch which can interrupt this current after the time
required to promote motor acceleration has elapsed.

For the motors in which very high efficiency is
required, this starting coil is not completely
5   switched off after the starting period has elapsed and
a capacitor, namely a running capacitor, is maintained
connected in series with said starting coil, providing
enough current to increase the maximum torque of the
motor and its efficiency.

10   For the motors with this construction, using a
permanent impedance in series with the starting coil
during the normal operation of the motor, there are
known some starting devices, such as PTC,
electromechanical relay, timers, or combinations in
15   which a PTC is connected in series with a device that
interrupts the passage of current after a determined
time (RSP), as described in US Patents 5,053,908 and
5,051,681 and in the international co-pending patent
application WO02/09624A1 of the same applicant.

20   One of the components widely used for starting the
motors of the split phase type, in which a running
capacitor is not used, is the electromechanical relay.
Its wide use is related to its low manufacturing cost
and simple technology. On the other hand, the
25   electromechanical relay presents several limitations,
especially the need of dimensioning a specific
component for each size of electric motor, the
impossibility of using it in high efficiency motors in
which a running capacitor is used, generation of
30   electromagnetic and other noises during operation of
the motor and wear of its components caused by
electric arc and mechanical friction.

An alternative for the electromechanical relay is the
PTC (positive coefficient temperature) device. This
35   component is widely used in high efficiency motors

whose application is associated with a running
capacitor. Since such component is a ceramic tablet
having no movable parts, its principle overcomes most
limitations of the electromechanical relay. Since its
5   operation is based on heating a ceramic tablet,
increasing its electrical resistance and consequently
limiting the circulating current, there occurs
dissipation of residual power during all its operating
time. Another limitation of this component is related
10   to the time interval required to allow consecutive
starts to occur.
One of the great advantages is the possibility of
using a single component to operate in the start of a
family of motors with a determined voltage (115V or
15   220V), but which becomes a limitation when the
analyzed characteristic is the optimization of the
energizing time of the auxiliary coil. Its conduction
time is directly proportional to the volume of the
ceramic tablet and inversely proportional to the
20   circulating current, resulting in a reduced starting
time when applied to high power motors, and in an
excessively long time when applied to smaller motors.
These two facts lead to a deficiency in the start of
the larger motors and to higher energy consumption
25   during the starting period of the smaller motors.
On the other hand, the timed starting components
eliminate the great disadvantage of the PTC residual
consumption, but do not overcome the deficiency in the
starting time required for the different motor sizes.
30   Its concept permits dimensioning a circuit which
provides the optimized starting time for the different
motor sizes. Thus, it is mandatory the existence of
several components to comply with a family of electric
motors, resulting in products of different models,
35   adjustments in the production lines, and higher

inventories. Such devices disregard the operating
conditions in the starting instant and are thus
dimensioned for the worst condition, increasing the
starting time.

5   Objects of the Invention
Thus, it is an object of the present invention to
provide a starting device having a simple, strong and
low cost construction, which permits: large scale
usage in low cost systems, presenting the advantages
10 of the timed devices in which the residual power
consumption is eliminated; reducing the number of
components so as to comply with a determined family of
motors having the same supply voltage; the use in high
efficiency motors with running capacitors; and which
15 presents the characteristic of the electromechanical
relays, in which the starting time is optimized for
each electric motor size.
It is a further object of the present invention to
provide a starting method for a single phase induction
20 motor, which optimizes the starting time as a function
of the size and load of the motor connected thereto.
It is a further object of the present invention to
provide a starting method for a single phase induction
motor,   which   optimizes   the   starting   time,
25 automatically, as a function of the power system
voltage.
It is a further object of the present invention to
provide a starting electronic device for a single
phase induction motor with negligible energy
30 consumption.
It is a further object of the present invention to
provide a starting electronic device for a single
phase induction motor, which can operate jointly with
a starting capacitor or other impedance installed in
35 series with the starting coil of the motor.

It is still a further object of the present invention
to provide a starting electronic device for a single
phase induction motor which is not susceptible to
transients or disturbances coming from the power
5   system.

Disclosure of the Invention

These and other objects are attained through a
starting device for a single phase induction motor
comprising: a stator having a running coil and a
10   starting coil; a power source which supplies current
to said running coil and said starting coil; a running
switch and a starting switch, respectively connecting
the running coil and the starting coil to the power
source when in a closed condition, said starting
15   switch being conducted to an open condition upon
completion of the motor start, said starting device
comprising a starting circuit including, besides the
running and the starting switches: a current sensor,
connected in series between the power source and the
20   stator, in order to detect the current level supplied
to the latter; and a control unit supplied by the
power source and receiving, from the current sensor,
signals representative of the current level being
supplied to the stator, said control unit being
25   operatively connected to the running and to the
starting switches, in order to instruct the open and
closed conditions thereof, the open condition of the
starting switch being defined when the ratio between
the present current level supplied to the stator and
30   informed by the current sensor to the control unit and
the starting current level previously informed to said
control unit by the current sensor upon the closing of
both the starting and the running switches, reaches a
value that is equal or inferior to a predetermined
35   value.

The objects of the present invention are also attained
through a starting method for single phase induction
motors of the type defined above, comprising the steps
of:

5   a- detecting the starting current level during a first
time interval, after the closing of the starting and
the running switches, by a current sensor connected in
series between the power source and the stator, and
informing said starting current level to a control

10   unit supplied by the power source and connected to the
current sensor, in order to receive, from the latter,
information about the current being supplied to the
stator;
b- detecting a present current level drawn by the

15   stator during a second time interval subsequent to the
first time interval after the closing of the starting
and running switches, and informing said present
current level to the control unit;
c- comparing the present current level drawn by the

20   stator with that value or the starting current level;
and
d- opening the starting switch when the ratio between
the present current level drawn by the stator and the
starting current level reaches a value that is equal

25   or inferior to a predetermined value.
The starting electronic circuit of the present
invention is of the type which comprises using a
mechanism for controlling the current consumption of
at least one of the motor coils during the running

30   period, storing the value read during the starting
period.
Such function can be obtained, for example by reading
the voltage drop provoked in a low impedance resistor
subject to the current consumed by the electric motor.

35   The electronic circuit further comprises using a

mechanism for monitoring the voltage of the power system, storing the value read during the starting period, in order to allow correcting the predetermined value, upon the occurrence of voltage variations in

5   the power system. Such function can be obtained, for example, by reading the voltage drop in a resistive divider.

As it is characteristic in an induction motor, at the moment in which it is connected to the supply voltage,

10   the current begins to circulate through the main coil and through the auxiliary coil. In this instant, the current consumed by the electric motor is highly increased, greatly sensitizing the mechanism that detects the current consumed by the motor. With the

15   beginning of the rotation of the electric motor rotor, caused by interaction of the magnetic field created by the current passing through both the running and the starting coils, the consumed current is gradually reduced to levels which will proportionally diminish

20   the sensitiveness of the consumed current detecting mechanism. This process will continuously progress, until the motor reaches the rotation speed close to the synchronous, in which the sensitiveness of the current detecting mechanism will be sufficiently low

25   to allow the circuit to switch off the starting coil. From this moment on, there will only exist current in the starting coil, provided by the running capacitor, if installed.

Since the current is recorded in each starting period,

30   the starting device is sensitive to the different torque levels required during the starting process, so that load variations in the motor shaft which can extend the starting period will maintain the energization in the starting coil during a period long

35   enough to overcome the restrictions imposed to the

electric motor. On the other hand, in a situation where the load condition imposed to the motor during said period is reduced, the rotor acceleration will occur in a shorter period, promoting a more
5   accentuated reduction in the current levels consumed by the electric motor, so that the device can disable the starting coil more rapidly.

Besides its susceptibility to load variation during the start, the solution of the present invention
10   further allows optimizing the energizing time of the starting coil for different supply voltages (undervoltage, nominal voltage or overvoltage) and for different temperature conditions of the electric motor windings.

15   Brief Description of the Drawings

The invention will be described below, with reference to the attached drawings, in which:

Figure 1 illustrates, schematically, an embodiment of a starting device constructed according to the present
20   invention;

Figure 2 illustrates, schematically, another embodiment for the starting device shown in figure 1 and constructed according to the present invention;

Figure 3 illustrates, schematically, current levels
25   being drawn by the motor stator and observed, as to time, during the start (t1, t2) and in a motor running condition, with the auxiliary coil energized (t3), and after the time (t3) with the motor running only with the main coil energized, obtained in the prior art
30   starting circuits for electric motors;

Figure 4 illustrates, schematically, current levels being drawn by the motor stator and observed, as to time, during the start (t1, t2) and in a motor running condition, with the auxiliary coil energized (t3), and
35   after the time (t3) with the motor running only with

the main coil energized, obtained with the present
starting device for electric motors; and
Figure 5 illustrates the flowchart of the starting
circuit logic.

5 Description of the Illustrated Embodiments
The starting device for a single phase induction motor
of the present invention will be described for a motor
comprising: a stator B having a running coil B1 and a
starting coil B2; a power source F, which supplies
10 current to both the running coil B1 and the starting
coil B2; a running switch S1 and a starting switch S2,
respectively connecting the running coil B1 and the
starting coil B2 to the power source F when in a
closed condition, said starting switch S2 being
15 conducted to an open condition upon completion of the
motor   start,   said   starting   device   comprising   a
starting circuit 10 including, besides the running
switch S1 and the starting switch S2: a current sensor
RS connected in series between the power source F and
20 the stator B, in order to detect the current level
supplied to the latter; and a control unit 11 supplied
by the power source F and receiving, from the current
sensor RS, signals representative of the current level
being supplied to the stator B and, from a voltage
25 sensor SV connected between the power source F and
said control unit 11, signals representative of the
voltage level of the power source F, said control unit
11 being operatively connected to both the running
switch S1 and the starting switch S2. According to
30 figure 1, the AC power source F supplies energy to the
running coil B1 and the starting coil B2 of the stator
B of the motor through a first supply terminal 1 of
the power source F, connected to the running coil B1
and to the starting coil B2 of the stator B, to the
35 voltage sensor SV, and to a supply source 12 of the

starting circuit 10 which supplies voltage to the
control unit 11. A second supply terminal 2 of the
power source F is connected to the current sensor RS,
which in figure 1 is disposed in series between the
5   power source F and the running and starting switches
S1 and S2. In another embodiment of the present
invention, illustrated in figure 2, the current sensor
RS is disposed in series between the power source F
and the running switch S1, in order to consider only
10   the current of the running coil B1 of the stator B.
This solution has the advantage of reducing the
current that is circulating through the current sensor
RS.

In an embodiment of the present invention, the
15   starting device allows using a running capacitor CR
disposed in parallel between a terminal T1 and a
terminal T2 of the stator B, which are respectively
associated with the running coil B1 and the starting
coil B2 of said stator B, so as to provide the
20   necessary time displacement between the currents
passing through said running coil B1 and starting coil
B2 during the normal operation of the motor, and a
capacitor CS disposed in series with the starting coil
B2 so as to provide said time displacement during the
25   motor start.

Once the circuit receives a switch-on command from an
external device, for example an electromechanical or
electronic thermostat 20, or by reading a temperature
sensor 30 adequately installed in the system, the
30   control unit 11 of the starting circuit 10 of the
present invention instructs the closing of the running
and the starting switches S1 and S2, in a synchronized
mode when the reading of the power system voltage is
zero, detected through the voltage sensor SV connected
35   to the control unit 11.

The running and the starting switches S1 and S2 are
closed in the instant the power system voltage is
zero, in order to reduce the current peak in said
switches and in the power system, avoiding generation
5   of electromagnetic noise and stress of said switches.
The running and the starting switches S1 and S2 can
have electromechanical contacts or static AC semi-
conducting switches, for example TRIACS.
The circulation of current through the motor, which
10 occurs through a current sensor RS, for example a low
impedance resistor, generates in the latter a voltage
or current signal that is proportional to the motor
current, which is then applied to the start circuit
10, for example in the form of an AD converter input,
15 not illustrated, of a micro-controller. During the
first cycles after the closing of the running and
starting switches S1 and S2, for motor supply, the
current is measured and the initial information of the
latter is obtained. During said period, the motor does
20 not reach a significant rotation and the current level
detected by the current sensor RS during these first
cycles is very close to the level which is
characteristic of the rotor blocked condition for this
type of motor, being then stored by the control unit
25 11 of the start circuit 10 as a starting current level
Ip. In this same time interval, there is also
obtained, through the voltage sensor SV, the
information of the voltage in the power system and
this value is stored as Vp. With reference to figures
30 3 and 4, the motor current remains approximately
constant during the first starting time interval t1,
after which, in a second time interval t2, the
measured current level begins to decrease gradually,
as the rotor begins to rotate. After reaching the
35 running regimen, close to the motor load condition,

the motor total current is stabilized, as indicated in figures 3 and 4 by a third time interval t3, when the starting coil B2 is still found de-energized.

After determining the starting current level Ip, which
5   occurs during the time interval t1, the present current level is continuously measured as Ia and the ratio between these values is constantly calculated as K;

10                  $$K = \frac{Ia}{Ip}$$

At each new detection of the present current level Ia, a new value for K is calculated. The first calculated
15 value for K will be very close to 1, since this present current level will occur in an instant immediately after the sampling which defined the starting current level Ip. While the rotor remains blocked, or is found much below the running rotation,
20 the present current level Ia will have a value close to that of the starting current level Ip, and consequently K will have a value equal or slightly inferior to 1. As the motor accelerates, the calculated K values diminish in the same rate as the
25 current of the stator B diminishes, which is a consequence of the CEMF (counter electromotive force) generated in the coils of the stator B as a function of the interaction with the currents in the rotor during its rotation.
30 Upon receiving each information about the present current level Ia drawn by the stator B, the control unit 11 calculates a ratio K between each said present current level Ia supplied to the stator B and informed by the current sensor RS to the control unit 11 and
35 the starting current level Ip, so that when said ratio

K reaches a value equal or inferior to a predetermined value Km, the control unit 11 instructs the opening of the starting switch S2, i.e., the ratio K is constantly compared with a predetermined value Km and
5   when K is equal or inferior to this value Km, the starting circuit 10 ends the motor start and the control unit instructs the opening of the starting switch S2.

The predetermined value Km is constantly adjusted by
10   the control unit 11 as being equal to the product of a reference value Kr multiplied by the ratio between the voltage read at the starting moment Vp and the present voltage Va, which voltages are detected by the control unit 11 by means of the voltage sensor SV,
15   mathematically:

$$Km = Kr. \frac{Vstart}{Vpresent}$$

20   If the voltage does not suffer alterations during the starting period, i.e., the present voltage Va is always equal to the starting voltage Vp, then the predetermined value Km will maintain the reference value Kr. However, if after the start the voltage
25   suffers alterations, for example diminishing, the current will suffer a less significant reduction at the end of the start, since besides the CEMF, the power system reduction factor will significantly influence the motor current. In this example, the
30   predetermined value Km is increased according to voltage variation. If, after the start the voltage increases, the motor current will not reduce accordingly, since the voltage increase causes a current decrease. In this case, the predetermined
35   value Km will be reduced to compensate for this

variation. With this logic, the circuit keeps the
starting coil B2 energized only during the time
required for the start, optimizing the start even when
fluctuations occur in the power system.

5   The reference value Kr is previously defined, as a
function of its application, family of motors, and
expected voltage of the power system and it can, for
example be defined between 0.2 and 0.8, depending on
the parameters mentioned above and on the circuit
10   topology: if the current measured is the total current
of the circuit or only of the running coil B2. The
reference value Kr is then defined during
implementation of the circuit as being the ratio
between a running current level Im drawn by the stator
15   B in a motor running condition, and said starting
current Ip for expected load conditions, type of motor
and power system voltage.

Figure 3 illustrates the motor current in one start,
presenting timing devices according to the prior art;
20   figure 4 illustrates the current during the start,
with the proposed solution; and figure 5 illustrates
the start logic executed by the circuit.

At each new motor start, a new starting current level
Ip is stored by the control unit, so that the circuit
25   can automatically adapt to the new conditions of load,
of power system voltages (overvoltage or undervoltage)
and to temperature conditions of both the running coil
B1 and the starting coil B2 of the stator B. Due to
the storage being made at each new start cycle, the
30   circuit does not require previous calibration for
certain motors whose operation is based on the
percentage reduction of the current value and not of
the current itself, so that the same circuit can be
applied to a wide range of motors.

35   In case an unsuccessful attempt to start the motor

occurs, in which the rotor remains blocked and there
is no reduction in the measured current value, the
control unit instructs the opening of the starting and
running switches S1 and S2 when the ratio between a
5   present current level Ia drawn by the stator B and the
starting current level Ip is higher than the
predetermined value Km, within a maximum time interval
which has been previously defined for ending the motor
start. In this condition, the first time interval t1
10 indicated in figures 3 and 4 will be unduly extended,
reaching a maximum allowed time, and the opening of
both the running switch S1 and the starting switch S2
will protect the motor and said switches. In this
case, the circuit will await the adequate motor
15 cooling time and/or the time required to adapt the
load condition to the torque delivered by the motor,
before allowing a new start cycle to begin.
During the normal operation of the motor, the current
is constantly measured and compared with a limit and,
20 if this limit is surpassed, the control unit 11 will
provide the opening of both the running switch S1 and
the start switch S2, protecting the motor.